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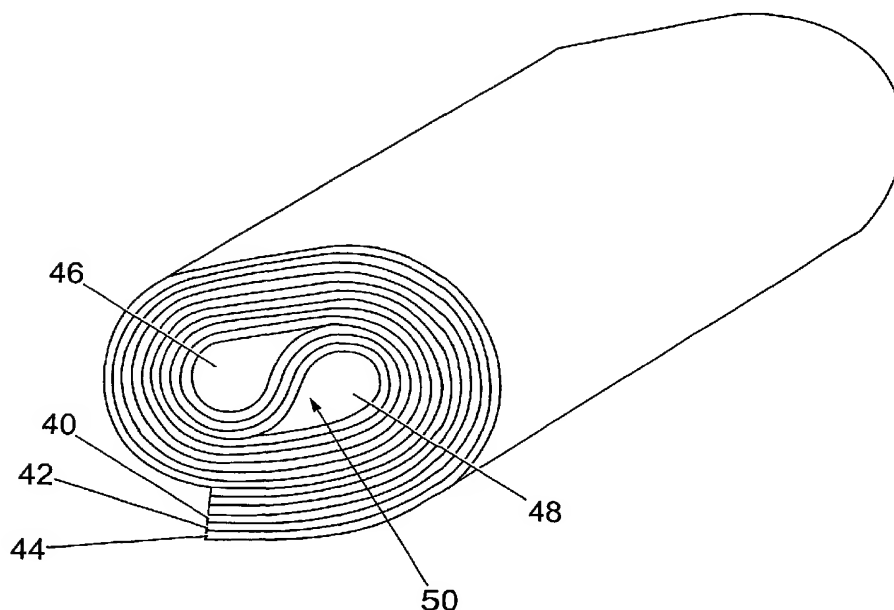
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[Continued on next page]

(54) Title: IMPROVEMENTS IN FUEL CELLS AND RELATED DEVICES



(57) Abstract: A solid electrolyte fuel cell component is formed by tape casting an electrolyte layer (42) and electrode layers (40, 44) to form a green tape which can be manipulated. The green tape is coiled into a form having an S-shape central portion (50) having oppositely-directed loops, so as to provide a first longitudinal channel (46) presenting an anode surface and a second longitudinal channel (48) presenting a cathode surface. After coiling, the assembly is fired to produce a solid, sintered product.



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1   "Improvements in Fuel Cells and Related Devices"

2

3   This invention relates to solid oxide fuel cells,  
4   and to devices similar to fuel cells for use in  
5   electrocatalysis and electrolysis in gas based  
6   processes.

7

8   Despite considerable research and development  
9   effort, fuel cells have not yet been successfully  
10   commercialised. Gradual progress has been made in  
11   developing solid oxide fuel cells in two basic  
12   arrangements, flat plate and tubular but costs  
13   remain high and there are sealing and interconnect  
14   problems.

15

16   The present invention seeks to provide a radical  
17   means of addressing these problems.

18

19   The present invention provides, in one aspect, a  
20   method of making a component having an anode, a  
21   cathode and a solid electrolyte, the method  
22   comprising using tape casting to produce a green

1 tape which is cohesive but flexible and firing the  
2 green tape to produce a rigid component; the green  
3 tape comprising at least three layers each of which  
4 is derived from a respective slurry comprising  
5 metal/ceramic particles dispersed in a carrier  
6 liquid.

7

8 From another aspect, the invention provides a  
9 component for use in a fuel cell or an  
10 electrochemical device, the component having a  
11 generally elongate tubular form divided by a central  
12 web into two channels, one of the channels  
13 presenting an anode surface to material flowing  
14 therethrough, and the other channel presenting a  
15 cathode surface to material flowing therethrough,  
16 the component further comprising a solid electrolyte  
17 between said anode and cathode.

18

19 The invention further provides fuel cells comprising  
20 components in accordance with, or made by the method  
21 of, the invention.

22

23 Preferred features of the invention and its  
24 advantages will be apparent from the following  
25 description and claims.

26

27 Embodiments of the invention will now be described,  
28 by way of example only, with reference to the  
29 drawings, in which:

30

31 Fig.1 illustrates the construction and operation  
32 of a known type of fuel cell;

1 Fig. 2 is a schematic side view showing an  
2 apparatus used for tape casting;

3 Fig. 3 is a similar view of an apparatus used in  
4 the invention;

5 Fig. 4 is a schematic perspective view of a fuel  
6 cell component in accordance with the invention;

7 Fig. 5A is a side view of a modified form of fuel  
8 cell component;

9 Fig. 5B is a side view of the modified component  
10 following a first step to produce a seal at one end;  
11 and

12 Figs. 5C and 5D are side and plan views,  
13 respectively, of the component following a second  
14 step.

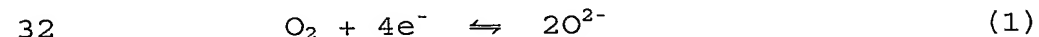
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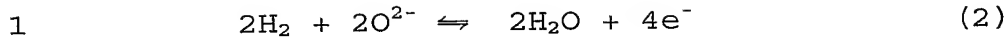
#### 16 Background

17

18 Referring to Fig. 1, a solid oxide fuel cell  
19 comprises an anode 10, a cathode 12, and a solid  
20 electrolyte 14. The cell produces electricity by  
21 electrochemically combining hydrogen (which may be  
22 present as such, or in a hydrocarbon fuel) and  
23 oxygen (which may be present as such or in air).  
24 The oxygen is reduced at the cathode 12, accepting  
25 electrons from the external circuit to form  $O^{2-}$  ions  
26 (equation (1)) which are conducted through the solid  
27 electrolyte 14 to the anode 10. At the  
28 anode/electrolyte interface, hydrogen is oxidised to  
29 form  $H_2O$ , releasing electrons back into the external  
30 circuit (equation(2)).

31





2  
3 Each of the three components must not react with any  
4 other component it is in contact with, must be  
5 stable at operating temperatures, and all three must  
6 have similar thermal expansions. The anode 10 and  
7 cathode 12 need high electronic conductivity and  
8 sufficient porosity to allow the gases to reach the  
9 electrode/electrolyte interface. In comparison, the  
10 electrolyte must be dense, preventing gas flow, have  
11 high oxygen ion conductivity, allowing  $\text{O}^{2-}$  ions to  
12 permeate with minimum resistance, and as small an  
13 electron transport number as possible.

14  
15 One known family of fuel cells uses yttria  
16 stabilised zirconia (YSZ). The anode consists of  
17 YSZ mixed with Ni, and the cathode of YSZ mixed with  
18 Sr doped  $\text{LaMnO}_3$ . This serves to obtain similar  
19 thermal expansion to the electrolyte, and also acts  
20 to increase the triple phase boundary (the area of  
21 contact between anodic/cathodic material,  
22 electrolytic material, and the gas phase).

23  
24 Two main types of fuel cell exist at present. One  
25 is the planar cell, in which flat plates in the  
26 geometry shown in Fig. 1 are stacked one on top of  
27 another separated by an interconnect. The other is  
28 tubular, in which the materials are formed into  
29 tubes with the inside surface cathode and the outer  
30 surface anode. Air and fuel (hydrogen source) are  
31 passed over the corresponding electrodes.

32

1   Preferred Embodiments

2

3   Turning to Fig. 2, the present invention makes use  
4   of a process of tape casting to form the electrode  
5   and electrolyte structures. Tape casting as a  
6   process is known *per se*, see for example 'Tape  
7   Casting Theory and Practice' by Richard E Mistler  
8   and Eric R Twiname, but has previously been used in  
9   the field of fuel cells only to manufacture single  
10  layers such as anodes or cathodes.

11

12  Tape casting is the production of thin sheets of  
13  ceramic and/or metallic material. The  
14  ceramic/metallic powders are mixed by ball mill  
15  together with various organic materials: solvent,  
16  dispersing agent, binder and plasticizer which hold  
17  the individual particles in a homogeneous  
18  distribution throughout the slurry.

19

20  As seen in Fig. 2, the slurry 20 is cast onto a  
21  moving carrier surface 22 by a doctor blade 24. The  
22  carrier surface 22 may suitably be a glass plate or  
23  Mylar sheet. Upon evaporation of the solvent, a  
24  flexible 'green' tape is produced which may be  
25  handled and manipulated. The green tape is  
26  subsequently fired, removing the remaining organic  
27  material and producing a hard, rigid sintered  
28  material.

29

30  The ball milling stage is important to ensure that  
31  all the soft agglomerates are broken down and the  
32  powder is well dispersed. The ball milling is

1 normally performed on the powder, solvent and  
2 dispersant; the binder and plasticizer added  
3 subsequently, and the entire mix may undergo further  
4 ball milling but at a slower speed. De-airing the  
5 slurry and maintaining a constant casting speed  
6 ensure constant thickness and smooth surface finish  
7 of the green tapes.

8  
9 Fig. 3 shows an apparatus in which three slurries  
10 20a, 20b, 20c are cast sequentially on a single  
11 carrier surface 22, thus producing a three-layer  
12 green tape which can be handled as a single unit and  
13 fired to produce a rigid unitary structure. By  
14 using suitable materials in the three slurries, a  
15 fuel cell component comprising anode, cathode and  
16 solid electrolyte is produced. A preferred  
17 composition is:

18	anode	YSZ and NiO which is reduced to
19		Ni under fuel conditions
20	cathode	YSZ and Sr doped LaMnO <sub>3</sub>
21	electrolyte	YSZ (8-10 mol% yttria, balance
22		zirconia)

23 One alternative to the multiple casting arrangement  
24 of Fig. 3 is as follows. The electrolyte layer is  
25 deposited first, and one electrode layer is  
26 deposited on top, once the electrolyte layer has  
27 partially dried. This composite is allowed to dry  
28 somewhat, after which the two-layer composite is  
29 turned over and the second electrode layer deposited  
30 on top.

31



1 Another alternative is to produce three separate  
2 ribbons by tape casting, and combine these by  
3 stacking and applying pressure, for example by  
4 passing between rollers. This has the advantage of  
5 further reducing the electrolyte thickness.

6  
7 The three layer structure produced by any of the  
8 foregoing methods forms a single component which can  
9 be handled and fired as a unit (co-fired). This  
10 contrasts with prior art use of tape casting, where  
11 each electrolyte or electrode layer is formed and  
12 fired separately.

13  
14 These fuel cell components can be produced simply by  
15 tape casting and firing, resulting in flat plate  
16 components. However, the invention also provides a  
17 novel form of fuel cell which is made possible by  
18 the use of tape casting.

19  
20 Referring to Fig. 4, a three layer tape having anode  
21 40, electrolyte 42 and cathode 44 is wound while in  
22 the green state prior to firing. The winding is  
23 such as to produce oppositely-directed loops in an  
24 S-shape in the centre of the component, thus forming  
25 longitudinal channels 46 and 48 separated by a  
26 central web 50. One channel 46 has a surface of  
27 anode material 40, while the other channel 48 has a  
28 surface of cathode material 44. Typically, the  
29 overall cross-section of the wound component may be  
30 about 50 mm, and the channels 46 and 48 each have a  
31 width of about 5 mm. The component may be wound  
32 from a tape 0.2m x 2m.

1  
2 In use, air is passed through the channel 48 to  
3 contact the cathode 44, and hydrogen (or a hydrogen-  
4 containing fuel) is passed through the channel 46 to  
5 contact the anode 40. The anode and cathode are  
6 porous, preferably about 50% porosity, and thus the  
7 air and hydrogen permeate through the anode and  
8 cathode layers and are not simply in contact with  
9 the parts fronting the channels 46 and 48.

10  
11 The arrangement shown in Fig. 4 thus provides a fuel  
12 cell component which is simple to make, gives a  
13 large active area within compact dimensions, and  
14 combines the best features of flat plate and tubular  
15 fuel cell geometries.

16  
17 Fig. 5 illustrates a modification of the embodiment  
18 of Fig. 4. This makes use of the fact that the  
19 electrolyte layer 42 is dense and impermeable. In  
20 Fig. 5, the electrolyte layer 42 is of greater width  
21 than the electrode layers 40 and 44 and thus forms  
22 projecting portions 42a, 42b when the layers are  
23 wound or coiled. The projecting portion 42a is  
24 pressed (Fig. 5A) to form a flattened end (Fig. 5B)  
25 which is then turned over (Figs. 5C and 5D) to form  
26 a seal, in the manner of a toothpaste tube. The  
27 assembly is then fired to form a rigid component  
28 sealed at one end.

29  
30 The projecting portion 42b at the other end may be  
31 used for connecting the component to a gas supplies  
32 such as fuel and air manifolds.

1

2 Choice of materials

3

4 The foregoing embodiment is based upon the use of  
5 YSZ materials. Such materials are presently  
6 preferred in carrying out the invention, and it is  
7 believed that the use of high-zirconia materials  
8 will be of particular benefit when using co-firing  
9 of multiple tape layers. However, other materials  
10 may be used in implementing the invention.

11

12 The electrolyte should be an ionically conducting  
13 oxide capable of transporting either oxygen ions or  
14 protons or both. Typical materials in addition to  
15 yttria-zirconia are scandia-stabilised zirconia,  
16 cerium oxide based materials, lanthanum gallate  
17 materials, and oxide proton conductors such as  
18 barium cerate, strontium zirconate, and other  
19 perovskites based on cerium, niobium or zirconium,  
20 and titanium containing alkaline earth strontium or  
21 barium or rare earths or yttrium or scandium.

22

23 Alternative air electrode materials would be based  
24 on lanthanum strontium cobaltate, lanthanum  
25 strontium iron oxide, and various combinations of  
26 manganese cobalt and iron in the same perovskite  
27 lattice.

28

29 The fuel electrode in addition to nickel zirconia  
30 cermets may use copper zirconia cermets, copper  
31 ceria cermets, nickel ceria cermets, perovskites  
32 based on lanthanum chromate, and fluorites based on

1 yttria zirconia titania either on their own or in  
2 combination with a current collecting material.

3

4 In summary, the invention may be applied to any  
5 oxide fuel cell having an electrolyte with solely  
6 oxide or/and proton ionic activity and electrodes  
7 with appropriate catalytic, electronic and ionic  
8 activity to function in the reduction of air (or  
9 oxygen or other oxidant) and the oxidation of  
10 hydrogen, hydrocarbon, reformed hydrocarbon or other  
11 appropriate fuel.

12

### 13 Process Examples

14

15 Some specific examples of tape casting YSZ-based  
16 slurries and tape processing will now be given.

17

18 Two sources of YSZ powder have been used. A first  
19 powder was obtained from Pi-Kem Ltd and has the  
20 following analysis:

21

22

TABLE 1

23

24		<u>wt%</u>
25	Y <sub>2</sub> O <sub>3</sub>	13.62
26	SiO <sub>2</sub>	0.01
27	TiO <sub>2</sub>	0.002
28	Fe <sub>2</sub> O <sub>3</sub>	0.003
29	CaO	0.002
30	Al <sub>2</sub> O <sub>3</sub>	0.25
31	Na <sub>2</sub> O	0.003
32	L O I	0.07

1

2

Balance: Zirconia

3

4

Average particle size: 0.21  $\mu$ m

5

Surface area: 6.9  $\text{m}^2/\text{g}$ 

6

7 The other powder was by Tioxide Ltd; no analysis is  
8 available. The powder by Tioxide Ltd was premixed  
9 with a binder, but the binder was removed by heating  
10 at 600°C overnight.

11

12 Particle size distribution was measured, without de-  
13 flocculation, by an LS Particle Size Analyser with  
14 detection limits of 0.4  $\mu$ m to 2000  $\mu$ m. 10 second  
15 ultrasonic agitation was performed prior to  
16 detection. The largest particles detected were 4  $\mu$ m  
17 (Pi-Kem Ltd) and 5  $\mu$ m (Tioxide Ltd) and both powders  
18 contained particles smaller than 0.4  $\mu$ m. The LS  
19 Particle Size Analyser showed the mode particle size  
20 to be 1.43  $\mu$ m (Pi-Kem Ltd) and 1.72  $\mu$ m (Tioxide  
21 Ltd).

22

23 A number of dispersing agents were investigated,  
24 namely tri-ethanol amine, citric acid, menhaden fish  
25 oil, oleic acid, phosphate ester (acid form), and  
26 polyethylene glycol. Tri-ethanol amine was found to  
27 work well with the Tioxide Ltd product, and  
28 phosphate ester (acid form) with the Pi-Kem Ltd  
29 product provided the quantity was kept below 1.5,  
30 preferably 0.05 - 0.12, g per 10 g of YSZ.

31

1 Tapes were produced using a planetary ball mill and  
 2 YSZ by Tioxide Ltd, with polymethyl methacrylate  
 3 (PMMA) and polyvinyl butyral (PVB) as binders. The  
 4 slurry compositions were as follows:

5

6

TABLE 2		
a) Binder: PMMA		
	Chemical	Mass/g (2 dp)
Powder	YSZ (Tioxide Ltd)	10.00
Solvent	Methyl ethyl ketone/ethanol (6:4 wt%)	5.20
Dispersant	Tri-ethanol amine	0.25
Binder	PMMA	2.24
Plasticizers	Polyethylene glycol (MW300)	1.62
	Di-butyl phthalate	1.46
b) Binder: PVB		
Powder	YSZ (Tioxide Ltd)	10.00
Solvent	Methyl ethyl ketone/ethanol (6:4 wt%)	5.20
Dispersant	Tri-ethanol amine	0.24
Binder	PVB	1.12
Plasticizers	Polyethylene glycol (MW300)	0.81
	Di-butyl phthalate	0.73

7

8 The tapes produced were flexible, with less binder  
 9 required when using PVB, showing PVB to have better  
 10 binding properties. For both tapes, ease of removal  
 11 was better from a glass carrier than from a Mylar®  
 12 carrier.

1  
2 Tapes with PVB binder were noted to be 'sticky' and  
3 if coming into contact with themselves were  
4 difficult to prise apart. TGA analysis showed both  
5 binders were completely removed by 600°C.

6  
7 The tapes were cut into sections and subjected to  
8 various firing rates and temperatures. They were  
9 fired flat, onto a Safil firing block.

10  
11 Slow heating of 1.5°C/min to 600°C, removing the  
12 organic material, greatly increased tape porosity.  
13 The PMMA binder tape has a larger pore size than the  
14 PVB binder tape, due to the higher binder: powder  
15 ratio. Both tapes were very brittle.

16  
17 Slow heating of 1.5°C/min to 600°C, rapidly heating  
18 to 1000°C (11.5°C/min) and holding at this  
19 temperature for 5 hours, again showed the tapes  
20 produced with PMMA binder to be more porous.  
21 Comparison to the tapes heated to 600°C show a  
22 decrease in porosity after the temperature increase  
23 as the tapes contracted. The tapes were less  
24 brittle after firing at 1000°C, but were still  
25 easily broken.

26  
27 Tapes were subjected to rapid heating of 11.5°C/min  
28 to 1000°C and holding at this temperature for 5  
29 hours. The tapes are still porous, but  
30 interestingly, there is an obvious decrease in  
31 porosity for tapes from PMMA binder and an increase  
32 in porosity for tapes from PVB binder without the

1 slow binder removal stage. Again, these tapes were  
2 brittle.

3

4 Sintering at 1500°C for 5 hours after slow binder  
5 removal reduced porosity further. The thickness was  
6 124  $\mu\text{m}$  (PVB binder) and the porosity of the PMMA  
7 tape to be much higher - reflected by the greater  
8 strength of the PVB binder tape. Both tapes  
9 sintered well. Impurities and many holes were  
10 present on both tapes. Impurities could be due to  
11 dust particles, or Si particles picked up from the  
12 furnace block.

13

14 A small sample of green tape was rolled according to  
15 the geometry in Figure 4, and fired to 1500°C.

16 Although the above flat tapes showed a smooth  
17 surface finish, the rolled tapes did not. This was  
18 thought to be due to too fast a heating rate causing  
19 the organic material to bubble leaving bumps on the  
20 surface.

21

22 Intense mixing of the planetary ball mill is thought  
23 to have adverse effects on the binder and further  
24 tapes were produced using PVB binder for YSZ  
25 obtained from both Pi-Kem Ltd and Tioxide Ltd, with  
26 the rotary ball mill.

27

28 Green tapes produced with YSZ (Tioxide Ltd) by  
29 rotary and planetary ball mill were compared. Both  
30 ball mills produced a similar homogenous particle  
31 distribution, although more 'lumps' are seen in the  
32 planetary ball milled tape. This is possibly due to



1 the more effective mixing of the planetary ball mill  
2 meaning the slurry was mixed for too long. Mixing  
3 of the slurry after binder addition for too long has  
4 the effect of producing less dense tapes, due to the  
5 substitution of the dispersant by the binder causing  
6 the 'zipper bag' effect, where the binder wraps  
7 around a group of particles to form an agglomerate.

8  
9 The tapes were heated at 0.8°C/min to 600°C, then to  
10 1000°C at 1.5°C/min, followed by 3.5°C/min to 1500°C  
11 and sintered at 1500°C. The thickness of the tape  
12 sintered at 1500°C was found to be much less than  
13 the planetary ball milled sample at 82µm. Halving  
14 doctor blade gap height gave a decreased thickness  
15 to 45µm. Both tapes show a decrease in porosity  
16 when produced with the rotary ball mill.

17

18 Again, the tapes sintered well. However, localised  
19 holes were still present and impurities were seen in  
20 grain boundaries.

21

22 YSZ powder from Pi-Kem Ltd was milled in a rotary  
23 ball mill. The slurry composition was as follows:-

24

TABLE 3		
	Chemical	Mass/g (2dp)
Powder	YSZ (Pi-Kem Ltd)	20.00
Solvent	Methyl ethyl ketone/ethanol (6.4 wt%)	10.45
Dispersant	Phosphate Ester (acid form)	0.21
Binder	PVB	2.24

Plasticizers	Polyethylene glycol (MW300)	1.62
	Di-butyl phthalate	1.46

1

2 The green tape shows a higher porosity than the  
3 green tape produced from YSZ (Tioxide Ltd)  
4 particles. However, the relative viscosity of the  
5 two slurries, suggests that the YSZ (Pi-Kem Ltd)  
6 particles were much better dispersed.

7

8 The tape was shaped into the desired geometry  
9 (Figure 4). They were heated to 600°C at 0.5°C/min,  
10 then to 1000°C at 0.8°C/min, followed by heating to  
11 1500°C at 10°C/min and sintering at 1500°C for 5  
12 hours. In order to reduce the impurities, an  
13 alumina plate was placed between the firing block  
14 and the samples. Tape thickness was greater than  
15 the tapes produced by YSZ (Tioxide Ltd) at 76µm, and  
16 the tape was denser. Increase in thickness and  
17 density could be explained by decrease in slurry  
18 viscosity.

19

20 The main surface showed fewer impurities, but  
21 contained more holes. This could be attributed to  
22 the geometry effectively increasing tape thickness,  
23 hence more organic material having to pass through  
24 the outer surface.

25

26 It was found that towards the centre of the sintered  
27 rolled tape the layers of tape are in contact with  
28 each other and sintered together. However, the

1 outer layer is only in contact with the rest of the  
2 sample in small sections.

3

4 PVB was shown to be a more effective binder than  
5 PMMA for production of green tapes. The smaller  
6 quantities of PVB required with respect to PMMA lead  
7 to denser tapes.

8

9 The time-scale used for ball milling (recommended by  
10 'Tape Casting Theory & Practise' by Richard E  
11 Mistler and Eric R Twina) shows use of the  
12 planetary ball mill produces more porous films.

13

14 The increased number of holes in the rolled tape's  
15 surface may be reduced when fired with porous anode  
16 and cathode, providing an easier escape route for  
17 the organic material.

18

#### 19 Further Examples

20

21 The following examples of slurry formulations have  
22 been found to be better optimised than those  
23 presented above.

24

#### 25 **Electrolyte formulations**

26	YSZ	30.00g	
27	Solvent	14.50g	MEK:ethanol 6:4 by weight
28	Dispersant	0.195g	Triton 0.44
29	Binder	3.36g	PVB
30	Plasticisers	2.43g	polyethyleneglycol
31		2.19g	di-butylphthalate

32

## 1 Procedure

2 1. 14g solvent + powder + dispersant. Ball mill  
3 18hrs at about 160rpm.

4 2. Add plasticisers + binder + 0.5g solvent. Mix  
5 by vibratory mixer for about 20min. Ball mill for  
6 4hrs at about 100rpm.

7 3. De-air by rolling with no milling media at about  
8 6rpm for about 23hrs.

9 4. Cast on tapecaster TT-1000 from Mistler & Co.

10 Speed: 50%

11 Doctor blade height: 0.3048mm (0.012inch)

12 Carrier: Mylar

13

14 **Anode formulations**

15 YSZ 5.8633g)

16 NiO 7.2570g) weighed correct (by balance)

17 Graphite 4.0984g) to +/-0.0002g

18 Solvent 10.125g MEK:ethanol 6:4 by weight

19

20 YSZ:NiO equivalent to 60:40 of YSZ:Ni by volume on  
21 reduction

22

23 NiO+YSZ:graphite is 50:50 by volume

24

## 25 Procedure

26 1. Ball mill for 18 hours at 160rpm (ball mill has  
27 both rocking and rolling action) with

28 Binder PVB 2.52g

29 Plasticiser di-butylphthalate 1.643g

30 PEG 1.823g

31 Note: no dispersion agent added

1 2. De-air. Ultrasonic agitation 30min. Vacuum  
2 5inchHg (below atmospheric) 5min.

3

4 Modifications

5

6 The above description refers to electrodes each  
7 consisting of a single uniform layer of sintered  
8 material. However, each of the electrodes could be  
9 constituted by composite layers which together  
10 fulfil the functions of the electrode, namely  
11 catalytic performance, electrochemical performance,  
12 electronic conduction, and gas distribution.

13

14 The anode and cathode may each be formed by two or  
15 more tapes laminated together to provide a gradation  
16 of function. Also, meshes or ribbons may be  
17 interspersed between the plural tapes, the meshes or  
18 tapes being burnt out during firing to form gas  
19 distribution channels. Alternatively the tapes may  
20 be appropriately scored using a serrated doctor-  
21 blade to provide such channels. In one example of  
22 cathode, a porous layer is formed next to the  
23 electrolyte from a mixture of YSZ and lanthanum  
24 strontium manganite or other electrode material, and  
25 a current collection layer with built-in channels is  
26 deposited on top of this, made from lanthanum  
27 strontium manganate.

28

29 An alternative material to nickel may be used to  
30 bridge the gap between the high temperature of the  
31 fuel cell anode and the low temperature of the  
32 incoming gas stream, suitably materials based on

1 oxides such as lanthanum chromite. Indeed, the  
2 anode itself, or part of the anode, may be formed  
3 from oxide materials such as lanthanum chromite.

4

5

6

7 Summary

8

9 It will be appreciated that the process examples  
10 given above are by way of explanation of general  
11 principles, rather than precise examples of specific  
12 formulations. However, from this information the  
13 person skilled in the art will be able to arrive at  
14 suitable compositions and processes for practising  
15 the invention, with no more than routine  
16 experimentation.

17

18 Although the preferred form of the invention is the  
19 S-shaped looped coil as shown in Fig. 4, the  
20 invention also includes the production of flat plate  
21 fuel cell components by firing flat tapes.  
22 Moreover, by simple rolling up of tapes followed by  
23 firing, tubular fuel cell components may be  
24 produced.

25

26 Materials other than YSZ may be used, for example  
27 scandia stabilised zirconia or scandia + yttria  
28 stabilised zirconia, suitably 8 -14 mol% scandia +  
29 yttria, remainder zirconia; and other materials as  
30 discussed above.

31

1 Although described with particular reference to fuel  
2 cells, the invention may also be applied to devices  
3 for use in electrocatalysis or electrolysis in a  
4 range of gas based processes.

5

6 Other modifications and improvements may be made to  
7 the foregoing embodiments within the scope of the  
8 invention as defined in the claims.

1     CLAIMS

2

3     1.     A method of making a component having an anode,  
4     a cathode and a solid electrolyte, the method  
5     comprising using tape casting to produce a green  
6     tape which is cohesive but flexible and firing the  
7     green tape to produce a rigid component; the green  
8     tape comprising at least three layers each of which  
9     is derived from a respective slurry comprising  
10    metal/ceramic particles dispersed in a carrier  
11    liquid.

12

13    2.     A method according to claim 1, in which the  
14    component is a fuel cell component.

15

16    3.     A method according to claim 1, in which the  
17    component is a component for use in electrolysis or  
18    electrocatalysis of gas streams.

19

20    4.     A method according to any preceding claim, in  
21    which the green tape is formed by casting at least  
22    three slurries one on top of the other and allowing  
23    the carrier liquid to evaporate.

24

25    5.     A method according to any of claims 1 to 3, in  
26    which the green tape is formed by casting at least  
27    three separate ribbons and pressing these together,  
28    preferably by passing through rollers.

29

30    6.     A method according to any preceding claim, in  
31    which one or both of the anode and the cathode is



1     formed by plural layers cast from slurries of  
2     differing composition.

3

4     7.    A method according to claim 6, in which there  
5     is interposed between said plural layers a web or  
6     mesh of a material which burns away during firing to  
7     leave gas flow passages in the formed electrode.

8

9     8.    A method according to any preceding claim, in  
10    which the carrier liquid comprises a solvent  
11    optionally combined with one or more of a  
12    dispersant, a binder, and a plasticiser.

13

14    9.    A method according to any preceding claim, in  
15    which the particles in each of the slurries are  
16    based on yttria stabilised zirconia (YSZ).

17

18    10.   A method according to claim 8, in which the  
19    anode slurry comprises particles of YSZ and  
20    particles of Ni or NiO, and the cathode slurry  
21    comprises particles of YSZ and particles of Sr doped  
22    LaMnO<sub>3</sub>.

23

24    11.   A method according to any preceding claim,  
25    including the further step of manipulating the green  
26    tape to produce a desired shape before being fired.

27

28    12.   A method according to claim 11, in which the  
29    green tape is wound to produce oppositely directed  
30    loops in the centre of the component to form  
31    longitudinal channels separated by a central web,  
32    one of the channels being enclosed by an anode

1 surface of the tape and the other by a cathode  
2 surface.

3  
4 13. A method according to claim 11 or claim 12, in  
5 which the green tape is formed with an electrolyte  
6 layer wider than the electrode layers and protruding  
7 from one side thereof, and in which, before firing,  
8 the green tape is wound into a cylindrical form and  
9 the protruding electrolyte layer is closed upon  
10 itself to form a seal at one end of the component.

11  
12 14. A component for use in a fuel cell or an  
13 electrochemical device, the component having a  
14 generally elongate tubular form divided by a central  
15 web into two channels, one of the channels  
16 presenting an anode surface to material flowing  
17 therethrough, and the other channel presenting a  
18 cathode surface to material flowing therethrough,  
19 the component further comprising a solid electrolyte  
20 between said anode and cathode.

21  
22 15. A component according to claim 14, formed by  
23 winding a flexible tape having an anode layer, an  
24 electrolyte layer and a cathode layer to produce  
25 oppositely directed loops in the centre of the  
26 component to form said longitudinal channels  
27 separated by said central web.

28  
29 16. A component according to claim 15, in which the  
30 flexible tape is a green tape formed by slurry  
31 casting and solvent evaporation; and after being

1     would the component is fired to produce a rigid  
2     component.

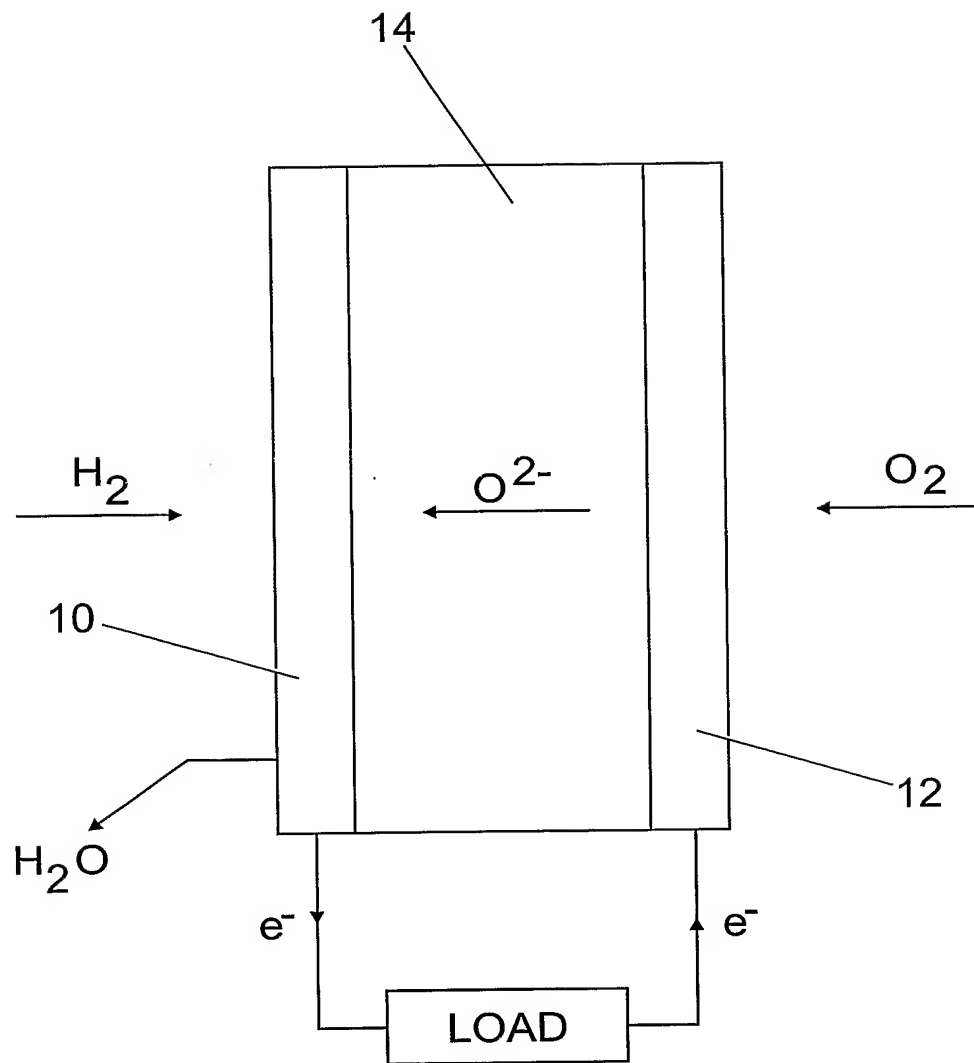
3

4     17. A fuel cell comprising a number of components  
5     as claimed in any of claims 14 to 16.

6

7     18. A fuel cell comprising a number of components  
8     made by the method of any of claims 1 to 13.

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*Fig. 1*

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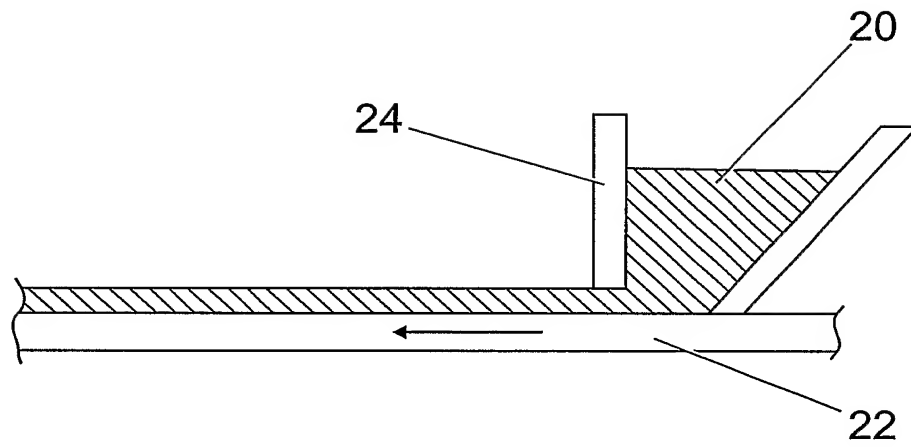


Fig. 2

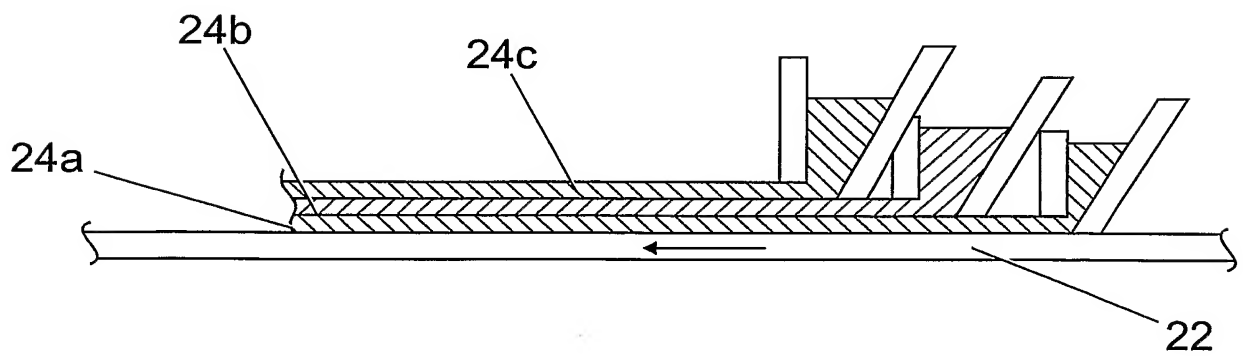
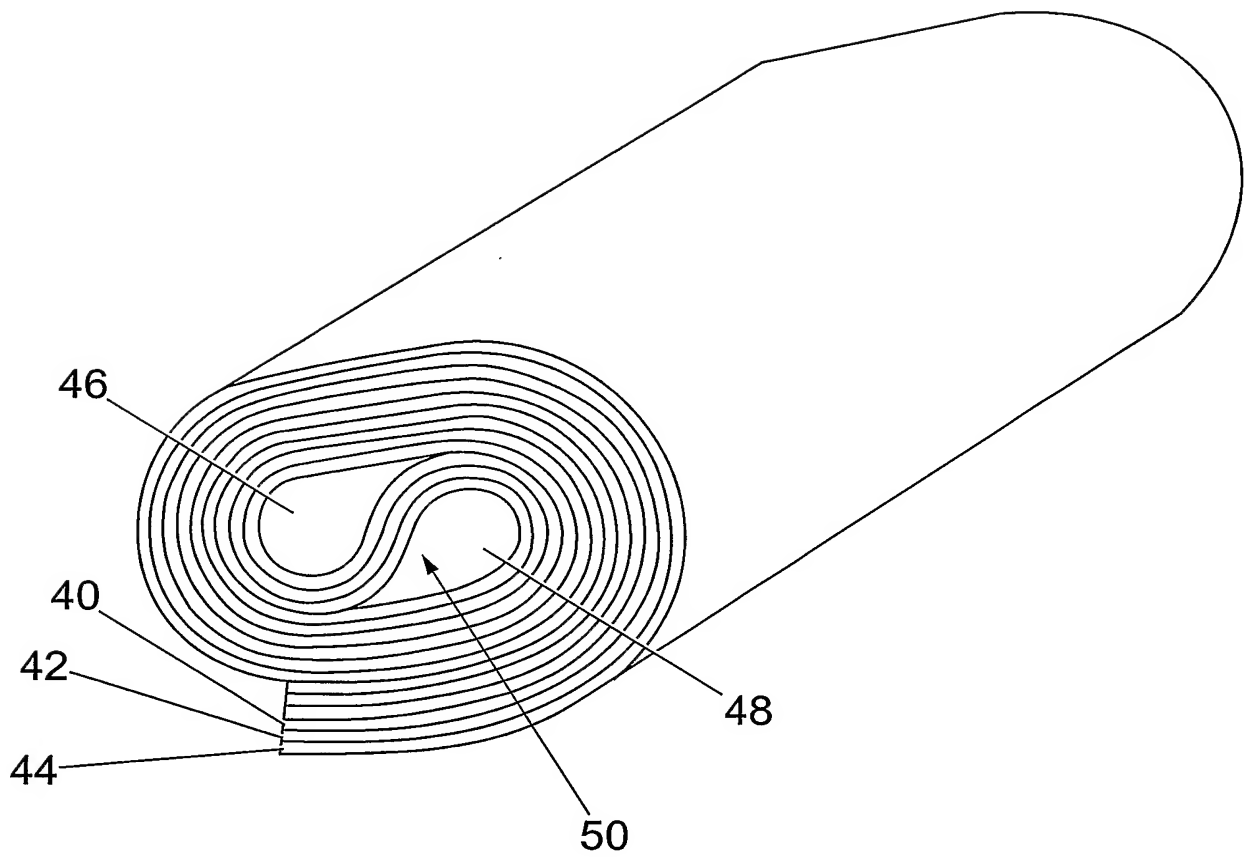


Fig. 3

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*Fig.4*

